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The Experimental Analysis of Inlet Parameters on the Performance of Liquid Desiccant Dehumidifier

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ABSTRACT: Dehumidification is the process of removing the moisture from air by chemical or physical methods. For a comfortable and healthy environment the two essential requirements are: adequate ventilation and good humidity control. But in very humid climates, which include much of the densely populated regions of the world, it is difficult to meet both these requirements without using a lot of electricity. One of the most common methods of dehumidification is the vapor compression system. The main disadvantage associated with vapor compression system is that it is an insufficient thermodynamic process. It requires the air to be cooled below its dew point, which lowers the temperature than needed to meet the sensible heat load. Thus, some source of additional energy is required to reheat the air to the desired delivery temperature. But liquid desiccant dehumidification technology removes the latent heat load directly from the air. The liquid desiccant is then regenerated, again by using low grade heating source like solar energy. In addition to dehumidification, an added benefit of some desiccants is their ability to absorb inorganic and organic contaminants in the air. The effect of various inlet parameters is analysed in this paper.

***Keywords**:* Energy, desiccant, humidity ratio, air conditioning, dehumidification systems.

I. INTRODUCTION

Humidity control is important in many engineering applications, such as space air conditioning (AC), storage warehouses, process industries and many others. In space AC, where conventional vapor compression cooling is used, humidity control is often accomplished by cooling the air below its dew point. In hot and humid climates, this method is inefficient, since it should be followed by reheating the air to a safe temperature before it is introduced into the conditioned space. Hence, the evaporator in the vapor compression system operates at a lower temperature than is required to meet the sensible cooling load [1], leading to a lower coefficient of performance and, consequently, higher energy requirements. Likewise, the effectiveness of evaporative cooling relies heavily on the existence of low relative humidity conditions, being higher as the relative humidity decreases. Thus, the humidity puts an extra load on the vapor compression AC systems and renders the evaporative cooling systems ineffective. Furthermore, under high humidity conditions, energy efficient vapor compression systems that were designed to operate at higher evaporator temperatures have been found unable to maintain the indoor relative humidity within a comfortable range [1, 2].

This calls for dehumidifying the air prior to entering the evaporator. Separating the control of humidity and temperature by means of desiccants could result in energy savings, as well as improved humidity control [1]. Desiccants are chemicals with great affinity to moisture. They may be used effectively as a supplement to conventional vapor compression systems to remove the latent part of the cooling load. That is, desiccants are efficient in handling latent loads (reducing the humidity), whereas the evaporator of the vapor compression system is efficient in handling the sensible cooling loads (lowering the air temperature). Davanagere *et al.* [3] listed the advantages of using desiccant based systems as follows:

(1) very little electrical energy is consumed, and the sources of regenerating thermal energy can be diverse (i.e. solar energy, waste heat, natural gas); (2) they are particularly useful when the latent load is large in comparison with the sensible load; (3) a desiccant system is likely to eliminate or reduce the use of ozone depleting CFCs (depending on whether desiccant cooling is used in conjunction with evaporative coolers or vapor compression systems, respectively); (4) control of humidity can be achieved better than those cases employing vapor compression systems, since sensible and latent cooling occur separately;

(5) the cost of energy to regenerate the desiccant is low when compared with the cost of energy to dehumidify the air by cooling it below its dew point; and (6) improvement in indoor air quality is likely to occur because of the normally high ventilation and fresh air flow rates associated with the higher evaporator temperature employed. Also, desiccant systems have the capability of removing airborne pollutants.

A. Dehumidification Process

Desiccants are chemicals with great affinity to moisture. They may be used effectively to remove the latent part of the cooling load in vapor compression air conditioners. Thus, the desiccant dehumidification process can be used as a supplement to conventional vapor compression systems. That is, the desiccants are efficient in handling latent loads (remove the humidity), whereas the evaporator of the vapor compression systems is efficient in handling the sensible cooling loads (lowers the air temperature). Hence, separating the control of humidity and temperature by means of desiccants could result in energy savings, as well as improved humidity control as shown in figure 1.In addition, the desiccant dehumidification process is environmentally safe in comparison to VAC systems. VAC systems are responsible for greenhouse gas emissions and they may contribute to global warming.

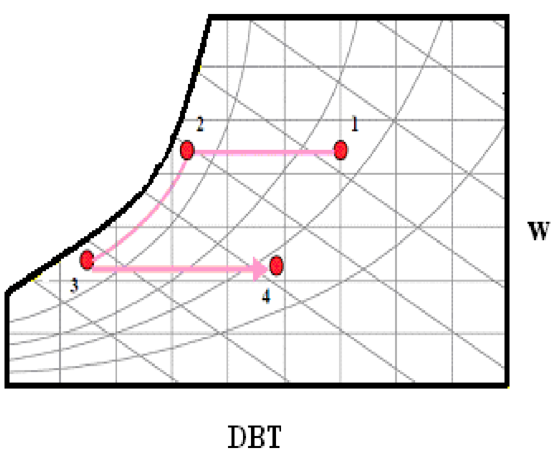

Fig. 1. Dehumidification Process on Psychometric chart.

The refrigerants (CFCs and HCFs) used in such equipment are them-selves greenhouse gases. It is possible that some of that refrigerant will escape into the atmosphere during routine installation, operation and servicing of the equipment. Once released to the atmosphere, the refrigerant has the potential to contribute to global warming. Moreover, most air conditioners are operated by electricity, and burning fossil fuels often produces this electricity. This burning process leads to the production and release of carbon dioxide that contributes to global warming. Due to the depletion of the ozone layer and global warming potential of these refrigerants, numerous alternative techniques are explored to conserve high-grade energy. One of these propositions that are energy efficient and environmentally benign is the desiccant.

B. Types of Desiccants

Several different materials can be employed as the desiccant, including both solid and liquid substances. Conventional solid desiccants include silica gel, activated alumina, lithium chloride salt, molecular sieves, titanium silicate and synthetic polymers. Liquid desiccants include lithium chloride, lithium bromide, calcium chloride and TEG. More details about desiccant types, properties and the regeneration process are given by Kinsara *et al*. [7].

C. Literature Review

The earliest liquid desiccant system was suggested and experimentally tested by Lof [8] using triethylene glycol (TEG) as desiccant. Solar-heated air was used for regeneration purposes. Sheridan [9] investigated a solar-operated liquid desiccant dehumidification-coolant using lithium chloride as the working fluid. Reviews of the early work on the development of liquid desiccant systems can be found in Gandhidasan and Gupta [10], Lodwig *et al*. [11].

The performance of a Liquid desiccant dehumidifier operating as an air dehumidifier is influenced by many inlet parameters and conditions [1,16], desiccant fluid characteristics (viscosity, density, and surface tension), packing type (shape, size and material), desiccant distribution over the packing, flow configuration (counter or co-current flow), tower height, fluid flow rates, and the inlet conditions of the desiccant (temperature and concentration) and the air (temperature and humidity).

To improve the effectiveness of the desiccant air dehumidification process, the impact of these parameters has to be evaluated. Good system performance and energy savings can be achieved if the proper values of these variables are selected. A number of experimental studies are reported in the literature regarding this matter. Furthermore**,** Zurigat *et al*. [12] carried out experiments on dehumidifiers with structured packing, using triethylene glycol as the desiccant.

In general, the usefulness of a particular liquid desiccant depends upon the application. For example, triethylene glycol does have a small vapor pressure that causes some of the glycol to evaporate into the air stream [13, 14].

The TEG vapor is thus carried over into the conditioned space and may condense on walls, windows and equipment, forming a viscous film. Furthermore, the viscosities of the glycol are much higher than that of the aqueous salt solutions and the pumping cost is also higher [15]. On the other hand, lithium chloride has good desiccant characteristics and does not vaporize in the air at ambient conditions. A disadvantage with lithium chloride is that it is corrosive.

Furthermore, there was a need to broaden the range of validity for these correlations by including additional experimental data. In the present work, the liquid desiccant ($CaCl_2$) was used as the working fluid. The work concentrated on carrying out experimental work to cover a wider and extended range of conditions reported in the literature. The study focused specifically on identification of the factors that regulate the water condensation rate and the dehumidification effectiveness in a liquid desiccant dehumidification system.

II. EXPERIMENTAL SET UP

The layout of the experimental set-up is shown in figure 2. for a recent study incorporated two separate solution tanks; a strong solution tank, which is connected to the top of the tower, and a weak solution tank, in which solution is collected from the bottom of the tower. The dimensions of the dehumidifier solution tank, which is made of Galvanized sheet are, are 60*30*90(L*W*H) cm^3. A strong aqueous $CaCl_2$ solution is supplied from the tank to the liquid distributor at the top of the packed column through a rubber hose. To control the solution flow rate, a throttle valve is fitted through the rubber hose.

Fig. 2.Experimental set-up.

The strong solution flowing through the packing is collected in the liquid collection basin which is connected to the lower end of the packed tower.

A square steel duct of (15x15) cm^2 cross section connects the air blower exit to the bottom of the tower (air stream inlet). The blower used in this experiment gives different air velocity with the help of electric regulator. Copper-constantan thermocouples are fitted at different locations .To measure the inlet and exit temperatures of both the air and liquid streams. Humidity ratio of air at inlet and exit is evaluated by measurement of air dry bulb temperature and wet bulb temperature. Also, the air stream velocity is measured using a U tube manometer. The solution concentration at the inlet and outlet of the packed tower is determined by measuring the solution density and temperature by specific gravity meter/Hydrometer.

The measured density at a given temperature is then used to find the concentration, which is measured with help of hydrometer. The liquid desiccant flow rate is measured with graduated rotameter.

A. Methodology

The operation and data collection are carried out as follows. First, the packed column is put into operation to bring the packing to the operating steady state temperature, the operating temperature of packing being dependent on the air inlet parameters (temperatures and velocity). Once the desired steady state condition of the regeneration process is reached, inlet and outlet parameters of air and solution are recorded. The usual time period for steady state to occur was from half an hour to one hour. Steady-state operation of the packed tower is achieved when the exhaust air temperature at the top of the tower and solution outlet temperatures are nearly constant ($\pm$0.1ºC).

Data being collected at time intervals of 15 min. In the air dehumidification mode the air conditioned to the required temperature and humidity at the air conditioning (AC) unit is introduced into the absorption tower from the bottom. The packing consisted of arrays of plates stacked in the column and oriented 90ºto each other. Three densities were used 150 m^2/m^3. Desiccant at the required temperature and flow rate is pumped into the top of the tower via the rotameter. The desiccant flowing countercurrent relative to the humid air flow is distributed over the packing and absorbs moisture as it comes into contact with the humid air. Uniform temperature and concentration of the desiccant are ensured using an electric heater with temperature controller and the circulation loop shown in figure2. The flow rate is monitored using a calibrated rotameter. The rotameter was calibrated under different desiccant temperatures.

The dry bulb and wet bulb air temperatures are monitored using mercury thermometers located at the inlet (bottom) and exit (top) of the absorption tower. Also, two more mercury thermometers are used to measure the inlet (tower top) and exit (tower bottom) desiccant temperatures. The air flow rate is monitored using an orifice flow meter (see Fig. 1). In any run, the inlet and exit temperatures and flow rates of both the desiccant and the air are measured after allowing sufficient time for steady state readings. Samples of the inlet and exit TEG solution are then collected. The TEG concentration is then determined using a Hydro meter. Before each run the entire absorption column including the packing, the thermometers, and the droplet arrester were cleansed using fresh water and then dried using warm and dry air supplied from the AC unit. The desiccant used in this work consists of pumping the CaCl2 solution, collected during the experiments. The entire process described above may be repeated until the required results are not achieved

IV. RESULTS AND DISCUSSION

The input variables used in the experiment were the independent measurable parameters, namely, entering air (temperature, humidity ratio, flow rate), solution (temperature, concentration and its flow rate). The principal results are output dependent parameters measured or calculated from experimental data. The measured outlet parameters are air exit temperature, humidity ratio, solution concentration and temperature, where as the calculated output variables are mass of evaporated vapour and vapour pressure on the solution surface.

A. Effect of Solution Flow Rate on Different Output Parameters

The effect of the solution flow rate on the output parameters of liquid and air streams is presented by keeping the other as constant like *t*si = 40°C, *x*i = 37.4 %, *t*ai = 30-33°C, wi = (15:15.8) g/kg. In these figures, it can be observed that the output parameters increase with an increase in the desiccant flow rate. Increased solution flow rate can be explained as follows:

For specific operating conditions and design characteristics of the tower, the heat transfer from heating stream of air increases with an increase in the flow rate of the liquid stream, therefore, air temperature increases. Although the heat transferred to the desiccant increases with an increase in the liquid flow rate, the outlet liquid temperature may decrease and consequently the vapor pressure on the liquid surface.

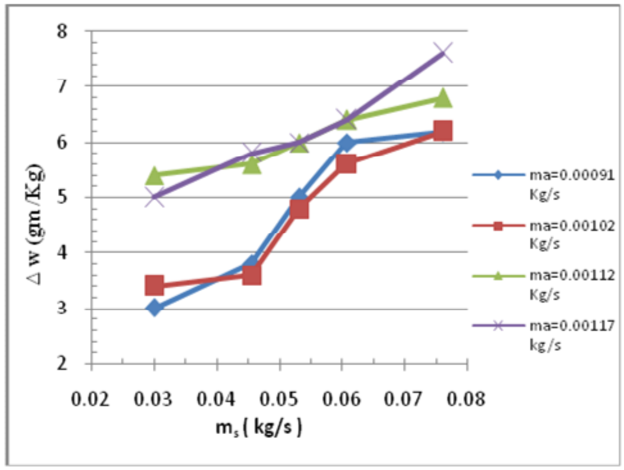

Fig. 3. Effect of solution flow rate on change in Specific Enthalpy at different air flow rates.

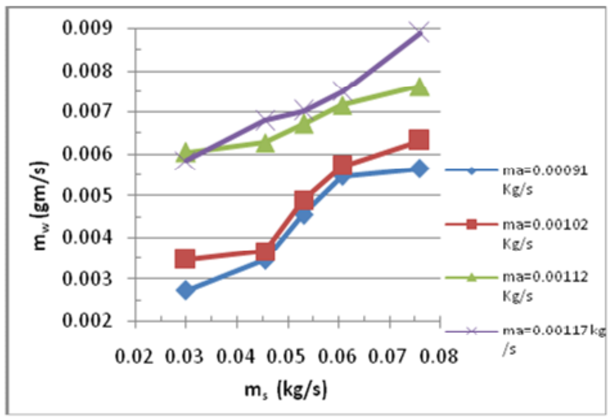

Fig. 4. Effect of solution flow rate on change on mass of condensate at different air flow rates.

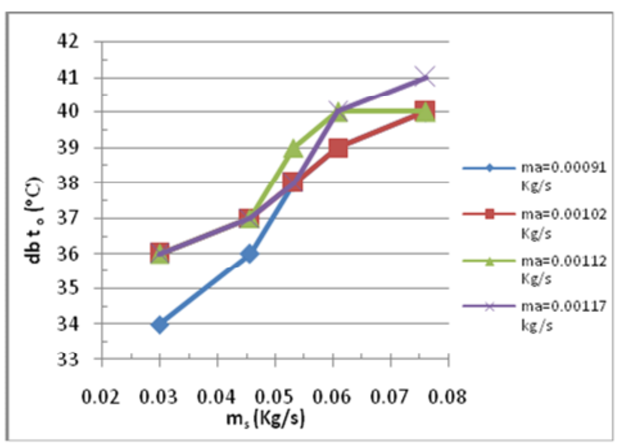

Fig. 5. Effect of solution flow rate on dry bulb outlet temp at different air flow rates.

B. Effect of solution inlet temperature on mass of condensate and change in specific humidity

The effect of solution inlet temperature on the output parameters is presented by keeping other parameters as constant like tsi=(40:36)ºC, m_s=(0.030:0.0761) kg/s, *x*i=37.4 %, *ma*=0.0009:0.0012) kg/s, wi=(15:15.8) g/kg. It is seen that the rate of increase of different parameters, with increasing in air inlet temperature, is higher than that observed earlier. The observed increase in solution output parameters, namely, solution temperature *t*so, and mass of moisture on different solution flow rates. The rate of heat transfer from the hot air stream to liquid increases and consequently raises the solution temperature. For the given inlet concentration, the higher the solution temperature, the higher the vapour pressure on the solution surface. The driving potential for the mass transferof the system is the vapour pressure difference between desiccant solution and hot air.

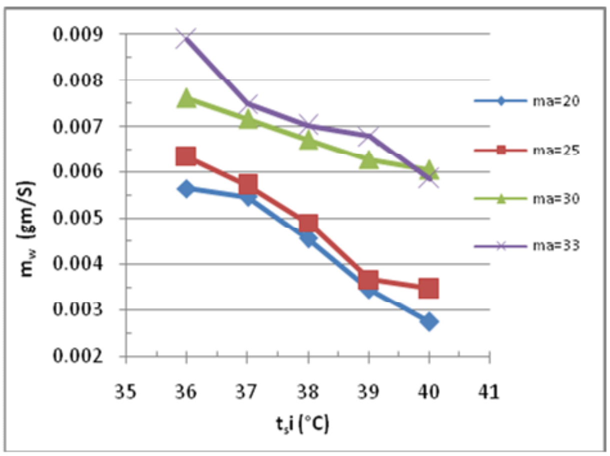

Fig.6. Effect of solution inlet temperature on the rate of water evaporation.

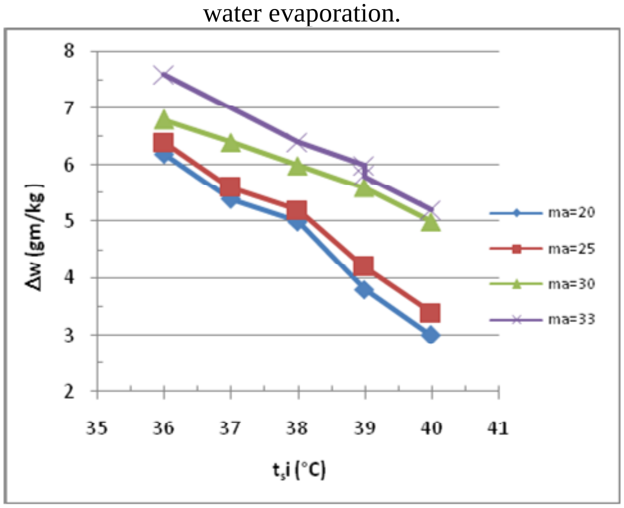

Fig.7. Effect of air inlet temperature on output parameters.

V. CONCLUSIONS

The performance of air dehumidifiers using calcium chloride ($CaCl_2$) as desiccant under hot and humid conditions was investigated. Structured packing was used to study experimentally the impact of a number of inlet variables on the performance of dehumidification process. The parameters that were considered were included air flow rate (m_a), desiccant

Inlet concentration (Xi), desiccant flow rate (m_s), desiccant inlet temperature (ts_i) and air inlet temperature (dbt_i). The performance of the dehumidifier was evaluated by calculating the moisture removal rate (m_w).

Finally, it can be concluded that a liquid desiccant dehumidification process would work best at high desiccant flow rate and concentration and low desiccant temperature, while the inlet temperature of the air and desiccant should be low. The air flow rate would be depending on the required ventilation rate whereas the inlet air humidity would be up to the ambient condition.

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